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Investment in Renewable Energy: Accounting for Climate Change

Gareth P. Harrison and Herbert W. Whittington

Abstract-- **The harnessing of renewable energy sources is key to constraining the extent of climate change. Unfortunately, the very fact that such sources are derived from climatic conditions may leave them vulnerable to changes in climate. In particular, their economic performance may be adversely affecting making them a less attractive prospect to investors. The potential for such changes is examined using hydropower as an example. A methodology is introduced that enables quantification of changes in investment performance following from changes in climate. Results of its use on a planned scheme indicate that investment measures show significant sensitivity to changes in rainfall, implying that, hydropower could become less competitive. Other technologies may show similar impacts and the investigation of them should now be a matter of importance.**

Index Terms-- **hydroelectric power generation, hydrology, meteorology, finance.**

I. Introduction

GLOBAL energy demand is expected to increase threefold over the twenty-first century [1]. Consequently, greenhouse gas concentrations look set to rise significantly, and by 2100 global mean temperatures may be between 1.4 and 5.8°C higher [2]. The impacts of such changes will be significant and far-reaching, and have prompted unprecedented international co-operation to control the rise in greenhouse gas concentrations [3]. These targets, and, in future, even more challenging targets, will require the energy sector to reduce fossil-fuel use, use more renewable energy and practice greater energy efficiency.

Over this century much new and replacement generating plant will be required to meet global demand. This will have to be achieved against in an environment of increased electricity supply deregulation and will require major investment from the private sector. As such, this means that the attitudes and perceptions of private investors will have an impact on the achievement of emissions targets.

A rising demand for electricity, likely increases in fossil-fuel prices and the need for clean emission-free generation sources all appear to be trends in favour of increasing generation from renewable sources. Currently, just over 20% of global demand is provided by production from hydroelectricity and other renewable technologies. There is a possibility that, by the end of the century they will supply between up to 70% of demand [1].

There are, however, several impediments that may prevent such a scenario from coming to fruition. Firstly, many renewable technologies have high capital costs and therefore their payback periods may be longer than preferred by private investors. Secondly, and potentially more importantly, the forecast changes in climate will directly affect the exploitation of renewable energy technologies through impacts on resource availability, operational performance and the 'willingness to develop' the resource [4]. These aspects are explored further in the next section.

II. Impact on Renewable Resources

Climate models suggest changes in a wide range of climate variables, from precipitation to cloudiness. As such, renewable technologies that rely on the climate to drive them will experience changes in the quantity and timing of the resource. Furthermore, energy installations are generally designed on the basis of prevailing climate conditions, which under different conditions may result in lower than anticipated production.

Many renewable technologies could be affected [4]. Solar energy technologies are sensitive to atmospheric conditions and increased cloudiness may reduce production capabilities. Wind regimes may alter and lower production from wind turbines where wind speeds do not suit the operating range. Ocean energy potential will be influenced by changes in wind speed, rising sea elevation and sea temperature and the development of new wave energy devices will have to take account of the forecast increased storm activity. There is also potential for biomass production to be affected by changes in growing conditions. However, the largest impact may be on hydropower generation as it is sensitive to the amount, timing, and geographical pattern of precipitation as well as temperature.

While there have been a wide range of studies, particularly on hydropower, these have focussed on the changes in the resource and the consequential impact on production. Until recently, there has been an apparent failure to address the third aspect, that of the 'willingness to develop'.

Historically, the development of renewable resources (i.e. hydropower) tended to be as part of wider social, political and economic programmes. In future, however, it will be economics more than anything else, that will govern which technologies contribute to energy supply. Given this, the authors have interpreted 'willingness to develop' to be the attraction of in-

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vesting in renewable resources. Where climate change leads to a reduction in renewable energy production, there is potential for the revenue stream to decrease, consequently lowering the financial return and making the technology less competitive.

Analyses by the authors have begun to quantify the economic impact of climate change on renewable technologies To date this has only featured hydroelectric developments, given their current and potential future role in electricity generation. The following section examines the potential hydropower impacts more closely.

III. HYDROPOWER IMPACTS

A. Changing River Flows

Changes in precipitation levels will be accompanied by increased evaporation rates as temperatures rise. The combination of these changes will have profound effects on soil moisture levels in river basins and consequently on river flows. Temperature rise will also lead to changes in snow storage, as proportionately less precipitation will fall as snow. Indications are that this will increase winter river flows, cause earlier spring thaws and reduce summer low flows [5]. Fig. 1 shows a hypothetical example of this.

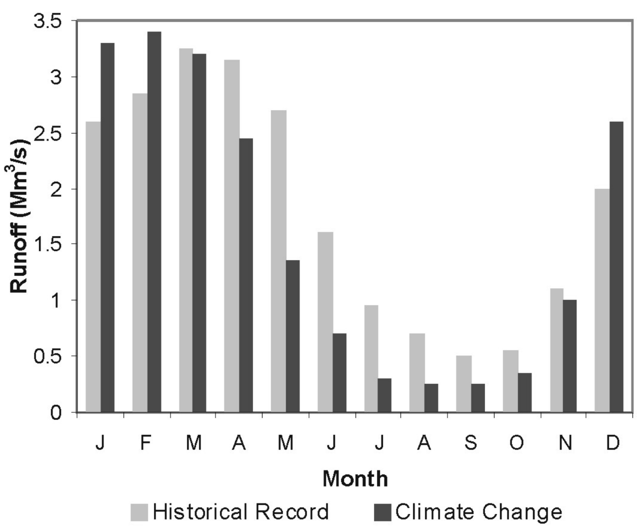

Fig. 1. Example of seasonal changes in runoff

Climate change impacts studies have generally used rainfall-runoff models to covert changes in precipitation and temperature into altered river flows. The changes can be based on results from General Circulation Models (GCMs) which provide information on how climatic variables may change in the future. As each GCM tends to predict a different change in temperature and precipitation, these often result in contradictory river flow impacts. As such, the examination of basin sensitivity to changing climate may be more appropriate. Despite differences between the study techniques used and the climatic and hydrological characteristics of the study rivers, several conclusions have been drawn [6]: that river flows are relatively more sensitive to precipitation change than temperature change, and that river basins tend to amplify changes in precipitation.

A 1995 study [7] examined climate impacts on several international rivers. The most severe impact saw the mean flows of the River Nile decrease to a quarter of historic levels. Overall, it was found that river basin sensitivity increases with aridity, which explained the severe fall in Nile flows.

Often seasonal changes are more profound. For example, a 1991 study [8] of a basin in central Greece found that a while one climate change scenario resulted in a 35% reduction in annual runoff, the decrease in summer flows was almost twice as large, with the fall in winter limited to around half. This pattern is repeated in many other studies and has serious implications for hydroelectric generation

B. Hydroelectric Generation Impacts

Hydropower production is defined by the river flow at a given site, so changes in flow will alter the energy potential. More importantly, as hydropower schemes are designed for specific river flow distributions, operation will become non-optimal under altered conditions. This occurs because the production capability is dictated by the storage, which places limits on the amount of carryover storage for generation during dry spells, and the turbine capacity, which specify the range of flows that over which the scheme can operate.

Several studies have examined climate change impact on production (Table I shows a representative sample). Published results suggest that the climate sensitivity of energy production is related to the available storage with greater storage tending to lower the sensitivity.

TABLE I
EXAMPLES OF IMPACT OF CHANGES IN CLIMATE ON ANNUAL PRODUCTION
(NOTES: * [9], ** [7]).

Annual Changes	Colorado*	Indus**	Nile**
Temperature (°C)	4	2	5
Precipitation (%)	–20	20	22
River Flows (%)	–41	19	–12
Production (%)	–49	20	–21

C. Investment Performance

Energy production changes of the magnitude suggested in the literature will have a major effect on station revenue. The sensitivity of revenue to changes in production depends on the electricity market structure in operation. For state-owned systems employing single energy tariffs, revenue will vary directly with production. With time-dependent prices, as in liberalised markets, a proportionately greater effect will be seen where variations in output coincide with high-price periods. In any case, if energy output falls, the tendency will be for higher unit costs, a lower return on investment and also longer payback periods. Essentially, the scheme's attractiveness to potential investors would be lessened and in the extreme case, potential schemes would not be pursued.

If potential hydro schemes are abandoned or production from existing facilities is limited by runoff changes, then alternative power stations will have to be constructed to cover the deficit. These are likely to be fossil-fuelled, given that the technology and fuel are, in general, readily available and, that their construction periods are relatively short. The consequence would be that additional carbon emissions would occur and exacerbate climate change [10].

Many large hydropower developments in less developed countries have been built with the intention of stimulating economic development. Often, these are internationally financed and repaid in hard currency. Reductions in revenue may make it difficult to repay the debt, putting pressure on exchange rates and stressing weak economies. Additionally, the shortfall in electricity availability will hamper Governments' development attempts [10]. All of these issues will almost certainly act as disincentives for Governments to exploit their hydroelectric resources.

The authors believe that the magnitude of capital investment required for hydropower installations, together with the increased demands of private capital, make it imperative that project analysis takes account of potential climatic effects.

IV. INVESTMENT APPRAISAL

Traditionally, hydropower appraisal employs historic river flow data as an indicator of future conditions. However, this reliance on historic flows is imprudent given the prospect of climate change. While several recent project appraisals have attempted to incorporate climate change by uniformly altering river flows, this practice is inadequate as it fails to take into account the tendency of catchments to amplify precipitation changes.

To overcome these shortcomings the authors have developed a methodology and have encapsulated the procedures in a software model, illustrated schematically in Fig. 2. A rainfall-runoff model provides a link between climatic variables and river flows, avoiding the reliance on historic flows and facilitating an effective examination of the relationship between climate and financial performance.

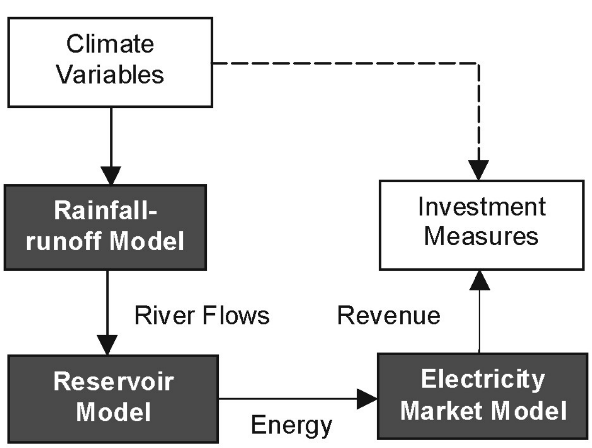

Fig. 2. Schematic of investment appraisal model

The data requirements for the model are extensive and include catchment details and time-series data. Historic climate data is the primary data source and experience has shown that at least 30 years are required to ensure that confidence can be placed on the results of the simulation.

V. SAMPLE ANALYSES

The Batoka Gorge scheme planned for the Zambezi River upstream of Lake Kariba (Fig. 3) was modelled using the software [11]. The 1600 MW plant is designed to operate in tandem with Kariba to provide maximum firm power on a system-wide basis and would produce 9,100 GWh annually [12]. Simulations show that the software provides estimates of production and financial performance that are in line with the feasibility study values. A series of analyses show the impact of changes in climate on the financial performance of the Batoka Gorge scheme [11],[13].

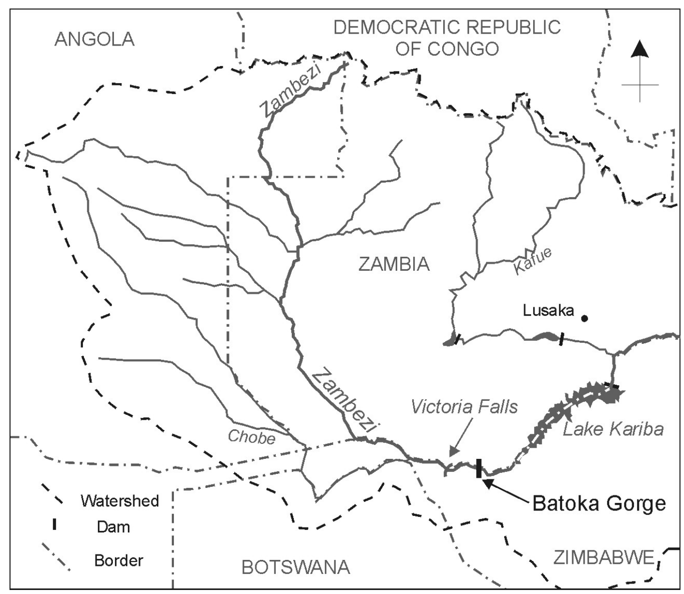

Fig. 3. Upper Zambezi River and Batoka Gorge

A. Sensitivity Study

The sensitivity study [13] featured the model being driven by historic precipitation and temperature data changed in a uniform manner to simulate climate change. Results suggest that river flows and energy production are sensitive to rainfall change, that runoff changes are significantly greater than the precipitation variation, and that, although reservoir storage is limited, production displays less sensitivity than river flows. It was also found that energy production is less sensitive to increases in flow as much of the excess flow is spilled.

The use of a single sales price for electrical production means that the investment sensitivity follows a similar pattern to production. Fig. 4 shows the response of internal rate of return (IRR) and discounted payback to rainfall variations. IRR is positively related to rainfall, whilst discounted payback period shows the inverse. The incomplete payback trace indicates that beyond a certain precipitation decrease, the payback period extends past the assumed appraisal time-scale. Net present value (NPV) varies in a similar manner to IRR, however, the compounding effect of revenue changes over the project lifetime means that the magnitude of the change is around ten times greater. Overall, the results indicate that the scheme remains financially viable so long as annual average precipitation reductions are not more than around 11%.

While the sensitivity to precipitation change appears to be significant, it is illustrative to compare it with other non-climatic project risks, e.g., variations in construction period or electricity sales price. Here, the sensitivity of the Batoka Gorge project to precipitation changes was similar to that of electricity prices and almost twice that for construction overruns. This implies that precipitation change poses a risk to financial performance.

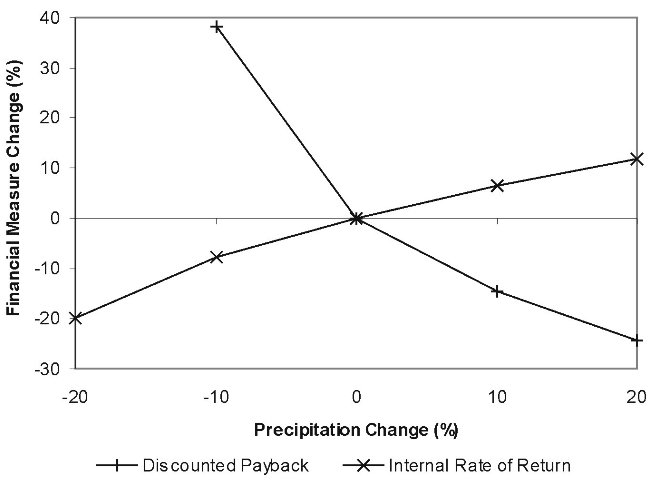

Fig. 4. Sensitivity of several scheme financial performance measures.

B. Climate Change Scenarios

The main drawback of the sensitivity study is that it does not consider that different variables may be inter-dependent. Scenario analysis [11] using climate scenarios taken from the results of General Circulation Models can correct this to some extent. Here three potential future climate scenarios (Scenarios 1 to 3) have been used to drive the model. Representing conditions in the 2080s, they project temperature rises of around 5°C accompanied by precipitation reductions of between 2% and 18% (Table II).

TABLE II
SUMMARY OF CHANGES WITH CLIMATE SCENARIOS

Changes	Scenario 1	Scenario 2	Scenario 3
Precipitation (%)	−2.0	−12.0	−18.0
Temperature (°C)	+5.0	+5.3	+4.4
River Flows (%)	−10.0	−28.0	−36.0
Production (%)	−6.0	−16.0	−21.0
NPV (%)	−62.0	−168.0	−220.0

All three scenarios have major impacts, the magnitude of which is determined by the degree of precipitation change (Table II). There are significant decreases in river flows and consequently smaller energy production levels. Such reductions in energy production have a major and detrimental impact, financially. Changes in IRR follow the production changes, and once again the impact on NPV is much greater. As can be seen in Fig. 5, all scenarios indicate very large reductions in project value. The smallest change is seen with Scenario 1, where even though precipitation decreases by only 2%, this causes NPV to fall by almost two-thirds. The much larger precipitation decreases suggested by Scenarios 2 and 3 result in significantly negative NPV values. In these cases, and on the basis of purely financial decision-making, the scheme would be regarded as non-viable and would not proceed.

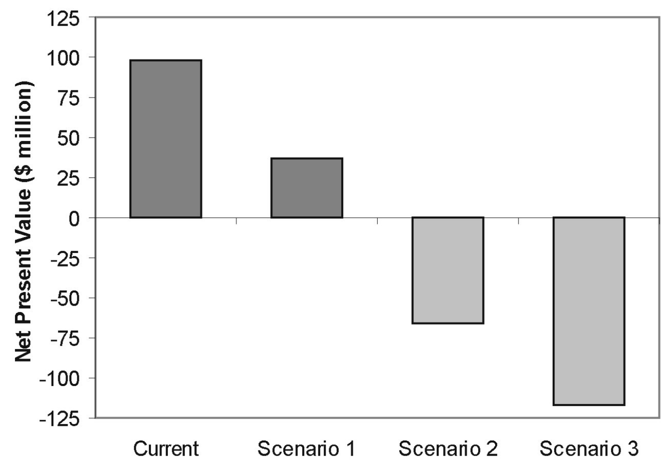

Fig. 5. Scheme net present value under several climate change scenarios.

C. Project Risk

Previous research [6] has noted that changes in precipitation tend not only to alter mean river flows but also their variance. The studies carried out on Batoka confirmed this and found further that monthly production and revenue variance was also altered. A preliminary study was conducted to determine whether such changes in monthly variance indicated changes in the financial risk faced by the project. Noting that synthetic river flow series are often used in water resources planning, a similar technique was applied to the historic climate time-series. Many statistically identical, but temporally different climate series were produced and applied to the model under current climate conditions and those indicated under the three previous scenarios.

From these simulations, the variances of the major financial measures were extracted and compared. For all three climate scenarios the variance of the financial measures increases, with variance increasing with the magnitude of the precipitation decrease. A further study [14] is underway to investigate this effect in more detail, given that the estimation of risk is a primary issue in determining the project discount rate, itself a critical factor in determining project viability.

VI. DISCUSSION

Although the results of the analyses are from a single scheme, they indicate that the financial performance of the hydroelectric scheme is sensitive to changes in precipitation patterns, implying that hydroelectric developments could become less competitive. If this were so, investment in hydropower projects would be less likely. The consequence would be that the ability to limit climate change will be reduced, firstly because hydropower is not used and secondly because increases in electrical demand will probably be met from fossil fuel burning.

The authors believe that similar impacts could be seen with other renewable technologies, and that similar methodologies for objectively analysing them should be developed and applied.

VII. CONCLUSION

Climatic change is expected to result from the release of significant quantities of man-made emissions of greenhouse gases. One of the key methods of limiting the extent of change is through the use of renewable energy sources. Unfortunately, the reliance of many renewable technologies on climatic conditions means that the changes predicted may affect, adversely, their future viability.

The potential for such an outcome has been illustrated by using hydroelectricity as an example. A methodology and associated model have been introduced which enable quantification of changes in investment performance following from changes in climate. Results of its use on a planned scheme indicate that investment measures show significant sensitivity to changes in precipitation, implying that, hydropower will become less competitive. Similar impacts may be seen with other renewable technologies and quantification of these should be considered a priority.

VIII. ACKNOWLEDGEMENTS

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IX. REFERENCES

[1] N. Nakicenovic, A. Grubler, and A. McDonald, Eds., *Global Energy Perspectives*, Cambridge: Cambridge Univ. Press, 1998.

[2] Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2001: The Scientific Basis*, Cambridge: Cambridge Univ. Press, 2001.

[3] UNFCCC, "Kyoto Protocol to the United Nations Framework Convention on Climate Change", UNFCCC, Bonn, Germany, 1998.

[4] R. A. Moreno, and J. Skea, "Industry, Energy and Transportation: Impacts and Adaption," in *Climate Change 1995 Impacts, Adaptations and Mitigation*, R. T. Watson, M. C. Zinyowera and R. H. Moss, Eds., Cambridge: Cambridge Univ. Press, 1996, pp. 365-398.

[5] P. H., Gleick, "Methods for evaluating the regional hydrologic impacts of global climatic changes," *J. Hydrology*, vol. 88, pp. 97-116, 1986.

[6] N. Arnell, *Global Warming, River Flows and Water Resources*, Chichester: Wiley, 1996.

[7] W. E. Reibsame, K. M. Strzepek, J. L. Wescoat Jr., R. Perritt, G. L. Gaile, J. Jacobs, R. Leichenko, C. Magadza, H. Phien, B. J. Urbiztondo, P. Restrepo, W. R. Rose, M. Saleh, L. H. Ti, C. Tucci and D. Yates, "Complex River Basins," in *As Climate Changes - International Impacts and Implications*, K. M. Strzepek and J. B. Smith, (Eds.), Cambridge: Cambridge Univ. Press, 1995, pp. 57-91.

[8] M. Mimikou, Y. Kouvopoulos, G. Cavadias and N. Vayianos, "Regional hydrological effects of climate change," *J. Hydrology*, vol. 123, pp. 119-146, 1991.

[9] L. L. Nash and P. H. Gleick, "The Colorado River Basin and Climatic Change: The Sensitivity of Streamflow and Water Supply to Variations in Temperature and Precipitation," US Environmental Protection Agency, Washington, D.C., Rep. EPA230-R-93-009, 1993.

[10] H. W. Whittington and S.W. Gundry, "Global climate change and hydroelectric resources", *IEE Engineering Science & Technology Journal*, vol. 7, no. 1, 1998, pp. 29-34.

[11] G. P. Harrison and H. W. Whittington, "Vulnerability of hydropower projects to climate change," IEE Proc. Gener. Transm. Distrib., in press.

[12] Batoka Joint Venture Consultants (BJVC), "Batoka Gorge Hydro Electric Scheme Feasibility Study Final Report," Zambezi River Authority, Lusaka, Zambia, 1993.

[13] G. P. Harrison and H. W. Whittington, "Sensitivity of hydropower performance to climate change," *J. Water Resour. Plng. and Mgmt*, submitted.

[14] G. P. Harrison and H. W. Whittington, "Climate change impacts on financial risk in hydropower projects", in preparation.

X. BIOGRAPHIES

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